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Carbon in the pregalactic epoch and the search for the first haloes

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ABSTRACT
A possible way of detecting the first structure formation in a non-standard BBN Universe during the dark age, due to the resonant scattering of the CMBR photons in the rotational lines of the primordial CH molecule is discussed. The calculations are made within the framework of the ΛCDM cosmology and plausible first structure physical conditions. The carbon chemistry during the pregalactic epoch is considered. The relative abundance of the CH molecule is found to be 10^{-14} whereas the adopted [C]/[H] ratio was taken to be 10^{-10}. The optical depth, dT/T and integration times are estimated. The calculated optical depth turns out to have values that are rather high, that clearly argue in favor of this molecule as an excellent candidate in searches of first structure formation. Possible observations with the GMT and ALMA are discussed.

Key words: cosmology: first stars, galaxies: formation, molecular processes

1 INTRODUCTION

The investigation of the epoch of first structure formation in the early Universe is one of the most intriguing aspects of modern cosmology. The observational data on the physical conditions during the growth of the first structures, if detected, can give us extremely important information on the fundamental problems of the early Universe, such as inflation, Big Bang Nucleosynthesis (BBN) models (see for example the review by Steigman (2006) and reference therein), the formation of the first mini-galaxies (see Yoshida et al. (2005) for a review, as well as Mashchenko et al. (2006) and reference therein), first miniquasars (Kuhlen & Madau 2005) and PopIII stars (O'Shea & Norman 2007; Vasiliev & Shchekinov 2003; Yoshida et al. 2006). As has been discussed in previous works, the most promissing way to investigate this epoch is to search for primordial molecules produced by the Spectral Spatial Fluctuations (SSF) in the spectra of the CMBR, through resonant scattering of the CMBR photons. Recently, the possibility of detecting these lines with ODIN and Herschel satellites has been investigated by Maoli et al. (2005). They have also discussed the current observational situation for the molecules based on light elements. For further details, see Maoli et al. (1996), and the most recent calculations of the SSF due to the HD molecule in Núñez-López et al. (2006).

The SSF from molecules based on the light elements (such as H, D, He, Li) in the primordial gas has been discussed by several papers during the last decade. But perhaps, light elements are not the only species capable of leaving footprints in radio. In recent years, models of Non-standard Big Bang Nucleosynthesis (NBBN) and new physics have attracted considerable atention, motivated in part for the discrepancies that remain between the abundance measurements of ^4He and ^2H (Steigman 2006). The NBBN models predict a wide range of abundances for the heavy elements, which could be used to discriminate with future observational results, among the alternative models. In this regard, and for reasons that will be discussed in this paper, the abundance of primordial carbon appears to be of particular interest. One obvious reason, is related to the peak in abundances for the C N O group, whose height has a strong dependence on the NBBN model. In particular, the ^{12}C relative abundance can vary from $3 \cdot 10^{-14}$ for the standard BBN (see for example Lara (1998)), up to 10^{-9} (Rauscher et al. 1994). Recently the model of Inhomogeneous BBN has been revisited by Lara et al. (2006), where the relative abundance of ^{12}C has been found to be of the order of 10^{-12} (Lara 2007).

The chemistry of the early Universe has also been a subject of investigation during the last few years. For a review on this topic one may read Galli & Palla (1998) and more recently, the results for the deuterium chemistry in Galli & Palla (2002). But little effort has been done so far to consider the assumption of the NBBN, for which, the chemistry of heavy elements has to be included.

Recently, the chemistry of the primordial carbon and

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oxygen in the early Universe was calculated (Lipovka et al. 2002a) and the possibility of direct observations of the CH molecules formed in the first haloes was discussed (Lipovka et al. 2002b; Campos et al. 2006).

It needs to be stressed that it is not just primordial carbon which should be taken into consideration, but also carbon produced by primeval SN. First stars (PopIII) possibly appear at $Z \approx 20$, and must significantly enrich the environment with heavy elements. For example, Daigne et al. (2004), consider a model in which the relative abundance of ^{12}C at $Z = 19$ due to feedback can reach a value of $[C]/[H] = 10^{-4}$.

It should also be noted, that the formation epoch of the first stars can be pushed back to even higher redshifts due to the presence of ultra-high-energy cosmic rays which stimulated the formation of the first stellar objects, as it has been recently suggested by Vasiliev & Shchekinov (2006). If this is the case, one can think of significant abundances of carbon at very early epochs.

It is for these reasons, that the search for primordial carbon is of so special interest. On the one hand, the detection of primordial CH would help us discriminate among the NBBN models. On the other, it would allow us to obtain extremely important information about the formation of first structures in the Universe (such as minigalaxies, first stars, etc.).

The CH molecule is an excellent specie for this aim due to several reasons:

1) ^{12}C is rather sensitive to the NBBN model.

2) It is argued here that C stands a better chance for primordial chemistry than the other two species in the $C\ N\ O$ abundance peak of the BBN element distribution. Although N has an abundance a little bit higher than C, its negative ion N^- has a binding energy an order of magnitude lower than that of C^-, and the ratios for NH molecule formation are quite low. With respect to oxygen, its relative abundance is much lower compared with that of C (see Lara (1998)) and the molecules based on primordial oxygen are less interesting than those of CH (see also

3) CH has a rather high dissociation energy (3.46 eV) and a large dipole moment.

4) Because of the rather low densities in the cosmological gas there is no depletion chain $C-CH-CH_2-CH_3-CH_4$, like the one that exists in the interstellar medium. For this reason, the kinetics of the interstellar medium is significantly different to the cosmological one.

Several facilities being planned or under construction will cover the submillimeter and millimeter wavelenght ranges with high sensitivity. Examples of these are ALMA, CARMA, and the Large Millimetric Telescope (LMT), under construction in Mexico, whose radiometers will cover the range from 0.8 to 3mm. The redshifted rotational lines of the primordial CH molecule are expected to fall in the mm region, and the optical depths for first structures are estimated to be rather high. The feasibility of detecting CH in the near future, is one of the main reasons of why is so important to do detailed calculations for this molecule.

The aim of the present work is to draw attention to the problem of heavy elements in the early Universe, and to emphasize on the extremely important role primordial carbon plays in the investigation of the pregalactic epoch, as well as in the BBN models. Here we present for the first time, the complete chemistry for primordial carbon and calculate the expected footprints from first structure under formation in the rotational lines of the CH molecule on the basis of the Λ - Cold Dark Matter (ΛCDM) scenario of cosmic structure formation.

The paper is organized as follow: in the second section we present the early Universe chemistry of primordial carbon. In the third, the observational parameters for the first haloes in the dark age epoch are presented. Finally, the main conclusions are discussed in the fourth section.

2 CHEMISTRY OF PRIMORDIAL CARBON

The chemistry of the light elements under the standard BBN model has been discussed in several papers (see for instance, the review paper Galli & Palla (1998)Recently the chemistry of fluorine in the early Universe was investigated by Puy et al. (2007) (see also references therein for the standard light element chemistry).

The chemistry of the primordial carbon and oxygen in the early Universe was considered for the first time in Lipovka et al. (2002a). In the present work the primordial carbon chemistry is revisited to make it more complete and up-to-date with more recent data for the molecular processes. Within the framework of the Λ CDM Universe, the parameters adopted for the calculations are as follows: $\Omega_m = 0.27$, $\Omega_b = 0.04$, $\Omega_\Lambda = 0.73$ and $H_0 = 71$ km s^{-1}Mpc^{-1}. (e.g., Spergel et al. (2003). Standard BBN yields of the light elements are assumed for simplicity, since their deviation from the standard values do not significantly affect the carbon chemistry. The kinetic equation of the system written in terms of the redshift z is given by the following expression:

$$\frac{dx_i}{dz} = \frac{1}{H_0\,(1+z)\,\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}} \times \left[n_0\,(1+z)^3 \left(\sum_{k,l} x_k x_l R_{kli} - x_i \sum_{m,n} x_m R_{imn} \right) + \sum_k x_k R_{ki} - x_i \sum_m R_{im} \right], \quad (1)$$

where $dz = dt H_0\,(1+z)\,\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}$), n_0 is the density of the gas in the present epoch, x_i are the dimensionless relative abundances for the i species ($x_i = n_i/n_{tot}$), $R_{jki}(T_c)$ are the rates of the collisional processes $i+j \rightarrow k$, as functions of the kinetic temperature T_c, $R_{ji}(T_r)$ are the rates of the radiative processes (formation and destruction of the molecules by the CMBR photons characterized by the radiative temperature T_r). To calculate the kinetic temperature T_c we need to solve the following equation:

$$\frac{dT_c}{dt} = -2T_c H_0 \sqrt{\Omega_{M,0}(1+z)^3+\Omega_\Lambda} + \frac{2\,(\Gamma_{mol}-\Lambda_{mol})}{3nk} + \frac{\Theta_{ch}}{3nk} + \frac{2T_c}{3n}\left(\frac{dn}{dt}\right)_{ch} + \frac{8\sigma_t a_b T_r^4}{3m_e c} x_e\,(T_r - T_c)\,. \quad (2)$$

Here the first right-hand term is for the Hubble expansion of the Universe, the second one corresponds to heating (Γ_{mol}), or cooling (Λ_{mol}) of the gas by absorption or emission, the third term describes the heating (cooling) of the medium in exothermic (endothermic) chemical reactions, the forth one appears here to take into account the change of the primordial gas density due to chemical reactions which do not conserve the number of initial species. The last term is due to Thomson scattering. These equations solve the problem of molecular kinetics at the pregalactic epoch.

Let us now consider the formation (destruction) processes in more detail. For the present calculations we basically adopt the rate constant coefficients used in our previous paper (Lipovka et al. 2002a). Most of the rate coefficients are listed there, but a few important reactions were missed, and for others we have found better values for the rate constants. For this reason, we now include some new processes and adopt a new set of ratio constants for the present calculations.

2.1 Photodetachment

As it is well known for the case of hydrogen chemistry at low redshifts, the formation of molecular hydrogen through the negative ion H^- is an important mechanism. For this reason it is of particular interest to follow the formation - destruction processes for the negative carbon ion C^-. This is a rather stable ion, with a binding energy $D = 1.25eV$ (for comparison, the binding energy of H^- is $0.75eV$). It is destroyed by the radiative photodetachment process:

$$C^- + \gamma = C + e^- \tag{3}$$

The rate for this reaction has been computed from the corresponding crossection published by Moskvin (1964) and it is in excellent agreement with the experimental data. The threshold energy for this process is 1.25 eV, and the rate coeficient is given by the following expression:

$$R_{pd} = 3 \cdot 10^5 \frac{T_r}{300} \exp(\frac{-15000}{T_r}), [s^{-1}] \tag{4}$$

which is used in our calculations.

2.2 Radiative attachment

This is the main channel for the C- negative ion formation and it is given by the reaction:

$$C + e^- = C^- + \gamma \tag{5}$$

The crossection and the rate coefficient for this process were calculated by Janev & Van Regemorter (1974), but these authors were interested only in the low temperature region, thus retained in the expansion for the crossection only the first corresponding terms. This leads to incorrect behavior of the rate coefficient at high temperatures $T > 100K$, if compared with those for the H- negative ion. Namely, it decreases and abruptly drops at $T_k = 1500K$, which approximately corresponds to redshift Z=500. For this reason, we need to calculate this rate coeficient for a wider range of temperatures, from $T_k = 100K$ to $3000K$. We have calculated this rate coefficient in our paper (Campos et al. 2006) by using the principle of detailed balance and crossection for the inverse process - photodetachment (see above), as suggested by Moskvin (1964). In this way, we obtain a rate coeficient which has the correct behaviour with the kinetic temperature (approximately constant), like those for the hydrogen radiative attachment ($H + e^- = H^- + \gamma$). It can be aproximately described by the following expression:

$$R_{ra} = 1.53 \cdot 10^{-15} (\frac{T_r}{300})^{-0.03}, [cm^3 s^{-1}], \tag{6}$$

which is adopted in our model.

2.3 Associative detachment

There are two process of associative detachment of interest. The first one is

$$C^- + H = CH + e^-, \tag{7}$$

and the second is

$$H^- + C = CH + e^-. \tag{8}$$

These were adopted in our calculations with the rate constans $5 \cdot 10^{-10}$ and 10^{-9} $[cm^3 s^{-1}]$ respectively from the UMIST data base.

2.4 Other important reactions

Beside those mentioned above, we revisited and incorporated another process which was not taken into account in our previous calculation (Lipovka et al. 2002a). As it was mentioned in that paper, the main channel for the CH molecule formation (destruction) are neutral-neutral reactions $C(H_2, H)CH$ and $CH(H, H_2)C$. The most recent review and data on these processes was presented by van Harrevelt et al. (2002) (see also references therein).

As discussed by Lipovka et al. (2002a) one of the most important channels for the CH molecule formation, is the $C + H_2 = CH + H$ reaction. It was investigated in detail in the paper of Guadagnini & Schatz (1996), where the crossection for this process was suggested and excellent agreement with the experimental data was reported. The rate coefficient for this reaction is given by the following expression

$$R_1 = 1.16 \cdot 10^{-9} (\frac{T_r}{300})^{0.5} \exp(\frac{-14100}{T_r}), [cm^3 s^{-1}], \tag{9}$$

The inverse process $CH + H = C + H_2$ is the main channel of destruction for the CH molecule. The most recent theoretical data on crossections and rate coefficients were suggested by van Harrevelt et al. (2002), where a comparison with the experimental data was also made (see references therein). The most recent experimental data on this rate constant increases from $1.3 \cdot 10^{-11}$ $cm^3 s^{-1}$ at $T_c = 300K$ to $1.6 \cdot 10^{-10}$ $cm^3 s^{-1}$ at $T_c = 2000K$. This fact suggests a small barrier of about $0.05eV$ (van Harrevelt et al. 2002). The rate constant for this reaction, adopted in our calculations can be represented by the following expression

$$R_2 = 9.0 \cdot 10^{-11} (\frac{T_r}{300})^{0.3} \exp(\frac{-580}{T_r}) [cm^3 s^{-1}], \tag{10}$$

which is in good agreement with the experimental results for the rate constant of this process. It should be noted

here that in the UMIST database for Astrochemistry, another expression for this rate constant is adopted, but it has a discrepancy of almost an order of magnitude with the experimental data, as well as with the theoretical one for a temperature of 300K, and for this reason it cannot be accepted for our calculations.

2.5 Details of the calculation and the abundance of CH

The calculations of the molecular abundances were carried out for a wide range of redshifts for the following species involved in the CH molecule formation: H, H^+, H_2^+, H_2, H^-, e^-, H_3^+, He, He^+, HeH^+, C, CH, CH_2, CH_3, CH_4, CH_5, C^+, CH^+, CH_2^+, CH_3^+, CH_4^+, CH_5^+, C_2, C_2^+, C_2H, C_2H^+, C_2H_2, $C_2H_2^+$, $C_2H_3^+$, and C^- . Other species are negligible in the formation processes of the CH molecule because of their small abundances. In our calculations we use the hydrogen and helium abundances according to the Standard BBN and did not take into consideration deuterium and litium, because of their insignificant role in the CH molecule production. We include helium because of the importance of the HeH^+ molecular ion in the production of H_2 by the chain of reactions $HeH^+ + H = H_2^+ + He$; $H_2^+ + H = H^+ + H_2$. The BBN carbon abundance was adopted from the paper of Rauscher et al. (1994) to be equal $[C]/[H] = 10^{-9}$. It is an estimation which can be easy changed to other abundance ratios, because it appears linearly in the equations.

The results of the calculation are shown in Fig. 1 for the range of redshift from $z = 400$ up to $z = 10$. The relative abundance of the CH molecule is shown by a solid line and all the others by dashed lines. For convenience we do not show the H and He abundances, since they are approximately constant, and in this way it is possible to see the curves for CH, CH^+, etc. in more detail.

One can readily see in Fig. 1, that the relative abundance ratio $[CH]/[H]$ at low redshifts can be as high as a fraction of 10^{-13} in the case of an homogeneous medium. But naturally, inside a protoobject, the gas density is expected to be higher, and so the chemistry must be faster and the relative abundance of the CH molecule will appear within 10^{-13} and 10^{-9}. To finalize, it should be noted that the so called "minimum model" of CH chemistry, suggested in the paper of Lipovka et al. (2002a) is not complete at low temperatures, and more species (such as CH_2, CH_3, C^+, $CH^+CH_3^+$, and C^-) must be included in the calculations.

3 OPTICAL DEPTH AND OBSERVATIONAL ESTIMATES

It is well known that the largest resonant line opacities in homogeneous mass perturbations are produced when they are at their maximum expansion or turn-around epoch (linear stage of their evolution), when all parts of the protocloud participate in the line formation process.

Let us estimate the detectability of line features of the primordial CH molecule in protostructures yet in their linear or about-linear evolution regime, i.e. before gravitational collapse and first star formation. Here we calculate the CH resonant line opacities only at the turnaround epoch for

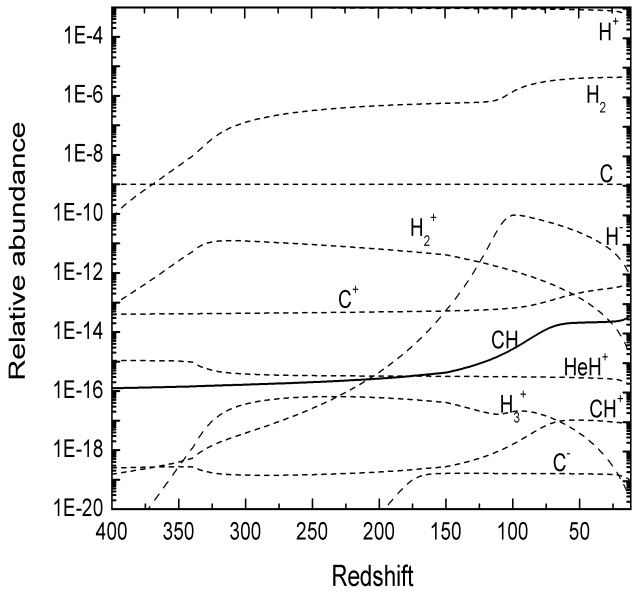

Figure 1. Fractional abundances of chemical species involved in the CH molecule formation as a function of redshift for an homogeneous primordial medium in concordance with a ΛCDM cosmological model.

CDM high-density $(6-\sigma)$ mass perturbations. The interaction of CMBR photons with the primordial molecules inside these protostructures will produce spectral - spatial signatures in the CMBR spectrum, containing information on the physical conditions of the gas prior to the formation of the first stars and minigalaxies in the universe.

The optical depths of primordial protoclouds in the rotational lines of CH molecule were calculated using the spherical top-hat approach (see for example Padmanabhan (1993); Tegmark et al. (1997), to obtain the epoch, density, and size of the CDM mass perturbations at their maximum expansion, for the ΛCDM cosmology. We have discussed the top-hat approach in our previous paper (see Núñez-López et al. (2006)), and here only the parameters of the first structures listed in Table 1 and Table 2 of that paper will be used. Table 2, in particular, present the parameters we need for 6σ halos: such as redshift of turn-around epoch, size of protoclouds, density etc.

The optical depth for a protocloud of size L is given by:

$$\tau_\nu(L) = \int_0^L \alpha_\nu dx, \tag{11}$$

where the integration is carried out over the line of sight and $\alpha_\nu(x)$ is the absorption coefficient given by the folloving expression:

$$\alpha_\nu = \frac{\lambda^3 (2J'+1)}{8\pi (2J+1) V_T} x_{CH} n_J n_{tot} A_{J'J} \left(1 - e^{\frac{-h\nu}{\kappa T_r}}\right). \tag{12}$$

Here λ is the wavelength, J is the rotational quantum number, x_{CH} is the relative abundance of the CH molecule shown in fig. 1, n_J is the population of J-th rotational level at epoch z, and $A_{J'J}$ is the Einstein coefficient.

By using these expressions, we calculate the CH line optical depths corresponding to protohalos of several masses at their turnaround redshifts. The result is

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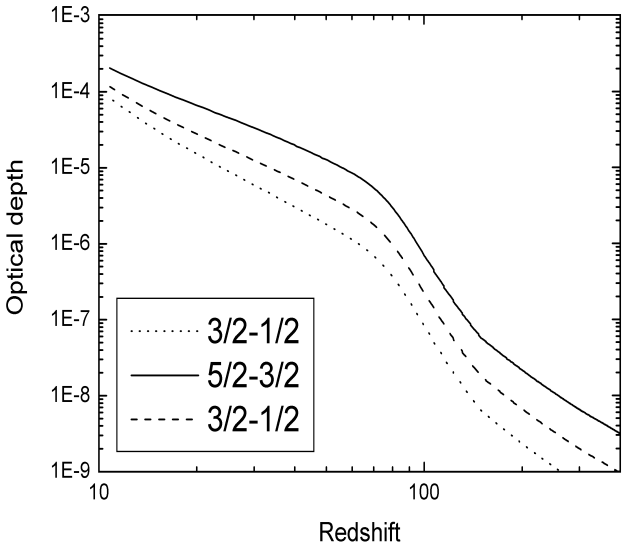

Figure 2. Optical depths in the first, second and third rotational transitions of CH molecule in 6σ ΛCDM protohalos of different masses reaching their maximum expansion at the redshifts shown in the abscissa. Dotted and solid lines correspond to the $^2\Pi_{1/2}$ state, and the dashed line is for $3/2(^2\Pi_{3/2})$ - $1/2(^2\Pi_{1/2})$ rotational transition.

shown in Fig. 2 for three ground rotational line transitions $3/2(^2\Pi_{1/2})$-$1/2(^2\Pi_{1/2})$, $5/2(^2\Pi_{1/2})$-$3/2(^2\Pi_{1/2})$ and $3/2(^2\Pi_{3/2})$-$1/2(^2\Pi_{1/2})$ for the 6σ first halos.

As one can see, the values of the optical depth for the CH molecular lines are rather large compared with those reported for the HD molecule (Núñez-López et al. 2006) and reach values 10^{-4} for the redshift $z = 20$.

Let us now estimate some observational parameters for the first structures in the CH rotational lines. The temperature fluctuations of the CMBR due to the resonance scattering of the CMBR photons by moving protoclouds is: (Sunyaev & Zel'dovich 1970)

$$\frac{\Delta T}{T} = \frac{V_p}{c}\tau. \qquad (13)$$

Here $V_p = V_p(z)$ is the peculiar velocity of the protocloud at epoch z with respect to the CMBR, c is the speed of light, and τ is the corresponding optical depth of the protocloud at epoch z_{ta} .

The linear theory of gravitational instability shows that the peculiar velocity of every mass element grows with the expansion factor as $V_p(z) \propto \dot{D}(z)/(1+z)$. An accurate approximation to this expression for a flat universe with cosmological constant is suggested in the papers of Lahav (1991) and Carroll et al. (1992). The value of the peculiar velocity at the present epoch $V_p(z=0) \approx 650$ km/s, adopted in our calculation, was taken from the papers of Lauer & Potsman (1994), Hudson et al. (1999, 2004); Willick (1999). By using this expression and the CH optical depths shown at Fig. 2, one can estimate with eq. (13) the temperature fluctuation of the CMBR secondary anisotropies. In our case for the redshift $z = 20$, for the case of the 6σ protohalos, we obtain that $\Delta T/T \approx\ 2 \cdot 10^{-7}$ in the 5/2-3/2 rotational transition at the restframe wavelength $\lambda_0 = 181\mu m$, whereas for the case of collapsed halos this value can be higher.

Let us now estimate the integration time required for the detection of the secondary anisotropies with modern telescopes (such as ALMA, CARMA or LMT/GTM submmilimeter telescope under construction in Mexico). The observational time ΔT can be estimated from the equation

$$\Delta T = \frac{T_n}{\sqrt{\Delta\nu \Delta t}}, \qquad (14)$$

where $\Delta\nu$ is the bandwidth, T_n is the noise temperature and ΔT is the amplitude of the temperature fluctuations calculated above. For $\Delta\nu$ we adopt an estimation $\Delta\nu/\nu \approx 0.1$ and $T_n \approx 50$ K. Thus, for the 6σ protohalos the integration time required to get an observable signal of the rotational transitions of CH molecules we estimate as $\Delta t \approx 7 \cdot 10^5 s = 200$ hours, which can be divided into 10 - 20 sets of observations near the north (south) pole regions. It should be stressed here that in the case of the collapsed gas inside virialized 3σ halos, previous to star formation triggering (see for detail the discussion in Núñez-López et al. (2006)), the integration time we need to detect the rotational lines of the primordial CH molecule, can be reduced up to some hours.

To conclude this part, the angular size of the objects must be mentioned. The first halos discussed in the present paper are actually the same considered in our previous paper (Núñez-López et al. 2006), in which the signatures of the HD primordial molecule were investigated. For this reason we do not need any special consideration here and can refer to Fig. 3 in that paper. It should be noted that the angular size for all protoclouds reaching their maximum expansion in the redshift range of $20 < z < 40$ (this corresponds roughly to a mass range of $10^5 < M/\mathrm{M}_\odot < 10^9$ and $10^9 < M/\mathrm{M}_\odot < 10^{11}$ for the 3σ and 6σ cases, respectively) appears within the observable region for ALMA and CARMA.

4 CONCLUSIONS

In the present paper we present for the first time the calculation of the kinetics of the primordial CH molecule and the observational estimates for protohalos during the first structure formation epoch, which can possibly be observed in the CH molecule rotational lines. This signature of the first

structure formation epoch is actually the Spectral-Spatial Fluctuations in the CMBR spectrum due to the elastic resonant scattering of the CMBR by primordial CH molecules in its rotational structure. The optical depths in the pure rotational structure of the molecule were calculated for the 6σ halos within the framework of a ΛCDM universe.

For our calculation, we adopt the relative abundance of primordial carbon $[C]/[H] = 10^{-9}$ taken from the paper of Rauscher et al. (1994). By taking into account the fact that the relative abundance of the CH primordial molecule depends linearly on the $[C]/[H]$ value, one can easy reestimate the results for any particular case of NBBN. The main results of this work can be listed as follows:

1) We calculate for the first time the chemistry of primordial carbon in the case of Non-standart BBN. This was done for an homogeneous primordial gas.

2) It is shown that the most abundant of the carbon-beared molecules is CH, whereas others (such as CH_2, CH_3, $CH_4, CH_5, CH_2^+, CH_3^+, CH_4^+, CH_5^+, C_2, C_2^+, C_2H, C_2H^+$, C_2H_2, $C_2H_2^+$) only appear in negligible amounts. This difference, if compared with the interstellar medium, can be explained in terms of the rather low abundances of primordial gas and carbon. It must be stressed that in the case of the presence of inhomogeneites, the CH molecule abundance increases, so that in this sense, our calculation can be considered as a lower limit estimation.

3) Within the framework of the ΛCDM universe we calculate the optical depth for the pure rotational lines of the primordial CH molecule for first structures formed during the Dark Age epoch. At redshifts $z = 20$, for the 6σ model, the calculated optical depth is $\tau_\nu \approx 10^{-4}$, in two ground and one exited rotational transitions. The frequencies of observation for these three lines are $\nu \approx 25, 80, 96GHz$ that correspond respectively to the redshifted lines of the rotational transitions $(J\prime J) = (3/2-1/2)$; $(5/2-3/2)$; $(3/2-1/2)$ of the CH molecule (see Fig. 2). Here we would like to stress the presence of tree observable lines with approximately equal optical depth, that would permit to justify the observed object as a first halo located at redshift $20 - 30$.

4) It is stressed that for testing the NBBN models, the CH molecule is the more eficient tool to search for the signatures of the first structure formation epoch, as compared with that of the HD molecule, discussed in our previous paper (Núñez-López et al. 2006). Besides that, the CH rotational lines (even if not detected) would allow us to discriminate between the NBBN models. The optical depth of first halos in rotational lines of CH in the case of NBBN model discussed in the paper of Rauscher et al. (1994), is larger than that for HD by factor 10^2.

5) In the case of the collapsed $3\sigma - 6\sigma$ halos (see Núñez-López et al. (2006)), the optical depth must increase $100 - 200$ times and the observational time would be reduced up to a fraction of one hour for the NBBN model of Rauscher et al. (1994), and probably even the model of IBBN suggested by Lara (2007) with $[C]/[H] = 3 \cdot 10^{-13}$ could be observed. By taking into account that the enhancement of the CH fractional abundance during the colapse of the protocloud, leads to detectable fluctuations in the CMBR temperature. For this reason it is of great importance to do detail investigation of the non-linear stages of collaps at the first structure formation epochs.

6) As it was mentioned above, the first stars (PopIII) possibly appeared at $Z \approx 20$, and significantly enriched the environments with heavy elements. In this case the relative abundance of ^{12}C at $Z = 19$ due to feedback can reach $[C]/[H] = 10^{-4}$ (Daigne et al. 2004). This high abundance is expected to be detected with modern radiotelescopes.

To conclude, we would like to stress again that the optical depths in the rotational lines of the CH molecule from the first structures depend strongly on the models of NBBN and structure formation, and that in some cases these lines might be observable today, whereas for others, not yet. In any case, this work has emphasized the need to search for signatures of this objects in order to find them or, at least to put an upper limits to constrain scenarios of formation and NBBN models.

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6 REFERENCES

REFERENCES

Campos J., Lipovka A., Saucedo J., & Zalkind V., 2007, to appear in Revista Mexicana de Fisica

Campos J., Saucedo J., Lipovka A., & Nunez Lopez R., 2006, proceedings of "Galaxy Evolution Across the Hubble Time", International Astronomical Union, S235, 251

Carroll S. M., Press W. H., Turner E. L., 1992, ARA&A, 30, 499

Daigne F., Olive K. A., Vangioni-Flam E., Silk J., Audouze J., 2004, ApJ, 617, 693

Galli D., & Palla F. 1998, Astron. Astrophys., 335, 403

Galli D., & Palla F. 2002, Planetary and Space Science, 50, Issue 12-13, p. 1197

Guadagnini R., & Schatz G. C. 1996, J. Phys. Chem., 100, 18944

van Harrevelt R., van Hemert M.C., & Schatz G.C., 2002, J. Chem. Phys., 116, 6002

Hudson M. J., Smith R. J., Lucey J. R., Schlegel D. J., Davis R. L., 1999, ApJ, 512, L79

Hudson M. J., Smith R. J., Lucey J. R., Branchini E., 2004, MNRAS, 352, 61

Janev R.K., & Van Regemorter H., 1974, Astron. Astrophys. v.37, pp.1-6

Kuhlen M., & Madau P., 2005, MNRAS, 363, 1069

Lahav O., Lilje P. B., Primack J. R., Rees M. J., 1991, MNRAS, 251, 128

Lara J.F., 1998, Stellar Evolution, Stellar Explosions and Galactic Chemical Evolution, Proceedings of the 2nd Oak Ridge Symposium on Atomic and Nuclear Astrophysics, 1997. Edited by Anthony Mezzacappa. Institute of Physics Publishing, 1998., p.123 ; arXiv:astro-ph/9806057

Lara J. F., 2007, Private communication

Lara J. F., Kajino T., & Mathews G. J., 2006, Physical Review D, 73, 083501

Lauer T. R., & Potsman M., 1994, ApJ, 425, 418

Lipovka A., Saucedo J., & Campos J., 2002a, Revista Mexicana de Fisica 48, 325

Lipovka A., Saucedo J., Campos J., & Soto I. 2002b, Astrophysics and Space Science Librerary 274, 73, Kluwer Academic Publishers

Maoli R., Ferrucci V., Melchiorri F., Signore M., & Tosti D. 1996, Ap.J., 457, 1

Maoli R., Chambaud P., Daniel J. Y., de Bernardis P., Encrenaz P., Masi S., Melchiorri B., Melchiorri F., Pagani L., Rosmus P., & Signore M. 2005, Proceedings of the dusty and molecular universe: a prelude to Herschel and ALMA, Paris, France. Ed. by A. Wilson. ESA SP-577, Noordwijk, Netherlands: ESA Publications Division, ISBN 92-9092-855-7, 2005, p. 293 - 296

Mashchenko S., Couchman H. M. P., & Sills A. 2006, The Ap.J., 639, 633., arXiv:astro-ph/0511361

Moskvin Yu. V. 1964, Opt. i Spektroskopia 17, 499

Núñez-López R., Lipovka A., & Avila Reese V. 2006, MNRAS 369, 2005 // astro-ph/0602474

Padmanabhan T., 1993, Structure Formation in the Universe. Cambridge Univ. Press, Cambridge

Puy D., Dubrovich V., Lipovka A., Talbi D., & Volanthen P. 2007, Astron. Astrophys. In press.

Rauscher T., Applegate J. H., Cowan J. J., Thielemann F.K., & Wiescher H., 1994, Ap.J., 429, 499

O'Shea B. W., & Norman M. L., 2007, Astrophysical Journal, to appear in January, astro-ph/0607013

Sunyaev R. A., & Zel'dovich Ya. B., 1970, Ap&SS, 7, 3

Steigman G. 2006, Int. J. Mod. Phys. E15, p.1

Spergel D. N., Verde L., Peiris H. V., Komatsu E., Nolta M. R., Bennett C. L., Halpern M., Hinshaw G., Jarosik N., Kogut A., Limon M., Meyer S. S., Page L., Tucker G. S., Weiland J. L., Wollack E., Wright E. L., 2003, ApJS, 148, 175

Tegmark M., Silk J., Rees M. J., Blanchard A., Abel T., Palla F., 1997, ApJ, 474, 1

Vasiliev E. O., & Shchekinov Yu. A. 2003, Astron. Rep., 47, 979

Vasiliev E. O., & Shchekinov Yu. A. 2006, Astron. Rep. 50, 778; 2006, Pisma Astron.Zh. 83, 872

Willick J. A., 1999, ApJ, 522, 647

Yoshida N. 2005, Progress of Theoretical Physics Supplement (PThPS), 158, 117

Yoshida N., Omukai K., Hernquist L., & Abel T. 2006, Ap.J. 652, 6. arXiv:astro-ph/0606106